Electric Heating Element For Hot Runner Systems And
A Method For Producing A Heating Element Of This Type

Specification

The invention relates to an electrical heating device for hot runner systems, in particular for hot runner manifolds and/or hot runner nozzles, according to claim 1. It further relates to a method of manufacturing such a heating device according to claim 24.

Electrical heating means for hot runner systems are usually separate component parts with tube-shaped heating elements which are integrated in detachable jackets for peripheral mounting onto flow ducts that commonly are tube-shaped. As disclosed e.g. in DE-U1-295 07 848 or in US 4,558,210, the jackets may be rigid structures whose radii of curvature match the flow duct, additional holding or clamping means being provided for fixing them on the tube periphery in an axial direction. Alternatively, they form flexible heating strips or heating blankets between electrically insulating layers which may have different heat conduction properties and which are fixed onto the tube periphery of the flow duct. EP-B1-0 028 153 provides heat conducting adhesive strips for the purpose, whereas WO 97/03540 employs flexible heating tapes having velcro or other snap fasteners.

Heating devices which in principle are mechanically detachable have the important drawback that heat transition from the heating element to the tube-shaped flow duct is frequently rather inefficient. For compensation it is necessary to enlarge the overall dimensions of the heating device, causing larger heat capacities. The resulting big thermal masses lead to prolonged heat-up and cool-down periods of time, whereby the growth of productivity rates is limited. Moreover, there are problems regarding linear temperature distribution within the walls of the flow duct which rarely feature a constant temperature throughout the length of the flow duct. In the region of the nozzle tip, in particular, sufficient heat transition and thus a sufficient level of temperature can be attained with large expenditures only. This, in turn, affects the entire temperature setting as well as the effort required for controlling means.

It is an object of the invention to overcome these and other disadvantages of the prior art and to create an electrical heating device for hot runner systems providing, between the main hot

runner portion and the nozzle, a heat transition and temperature distribution pattern that is generally improved and permits individual precise adjustment. The device is to be designed for easy operation without much effort for control means.

The invention further aims at providing, for hot runner systems, positively and non-positively integrated electrical heating means of compact design which are adapted to be non-detachably mounted onto a flow duct wall such as a mold mass flow tube, a rod, a manifold branch, etc. and which will permanently withstand even extreme mechanical and/or thermal loads.

Another important object of the invention is the development of a method of manufacturing heating devices for hot runner systems, especially for hot runner manifolds and/or hot runner nozzles, requiring a minimum of effort but permitting simple and economical performance.

Principal features of the invention are defined in claims 1, 22, 23 and 24.

In an electrical heating device for hot runner systems, in particular for hot runner manifolds and/or hot runner nozzles, the invention provides at least one insulating layer and at least one heating layer having heating conductors, these layers which form a flat layer heater being directly coated in an adherent manner onto at least one wall of a mold mass flow tube that is associated to a flow duct.

A method suited for manufacturing such a heating device for hot runner systems, in particular hot runner manifolds and/or hot runner nozzles, provides according to the invention that at least one insulating layer and at least one heating layer having heating conductors are directly coated in an adherent manner onto at least one wall of a mold mass flow tube that is associated to a flow duct.

Adherently depositing layers of the heating device results in a permanently fixed connection with the wall of the flow duct and thus in a secure fixing on the hot runner manifold or on the hot runner nozzle. The heating device requires only little room owing to the small thickness dimensions achieved through direct coating, whereby in comparison to conventional heating devices, and with almost equal features of performance, extremely compact embodiments can be realized. Moreover, the power density can be distinctly increased since heat is produced and carried off directly at the surface of the hot runner element to be heated. Together with the

fixing of the heating device on the flow duct wall in a mechanically non-detachable manner, all of this warrants an always optimal heat transition from the heating layer via the insulating layer onto the wall that is heated most uniformly and precisely. There is no need for expensive control means which would have to cope with reaction delays caused by thermal masses. The flow duct allows quick and accurate heating and cooling-off again, too, with favorable effects on the entire producing sequence. The melting temperature can be controlled exactly, using simple means.

Another advantage consists in that the heating device is reliably protected against moisture absorption. Conventional heating devices employing tubular heaters or helix tube cartridges pose, in addition to mounting problems, also insulation problems due to absorption of moisture in a hygroscopic insulating material, as penetrating moisture may cause shortcuts. In order to avoid this, additional control means are required for dewatering by initially operating the heating device under reduced heating power. The heating device of the invention does without that. Rather, it is joined to the flow duct in an absolutely tight and captivated manner so that the conventionally necessary effort for mounting and control is completely dispensed with. This has positive effects on the purchase and mounting costs.

Advantageous embodiments of the invention from the subject matter of claims 1 to 21 and 25 to 46.

Another important feature of the invention is the development of a tension-relief connection between the ceramic dielectric layer and the hot runner tube which under operating temperature is exposed to a pulsating interior pressure load technologically caused by the injection molding process. This load, and the need to heat the flow duct wall up to temperatures between 300 °C and 450 °C in order to reach operating temperatures, result in elastic expansions which are directly transferred to the heating device. The actual degree of deformation will depend on material-bound factors (e.g. elastic modulus) and on technical boundary conditions (operating temperature, tube wall thickness, level of interior pressure). This may bring about that layers deposited on a steel tube will, under the co-influence of the said factors, be exposed to tensile stresses, if to varying extents; the invention, by contrast, avoids this reliably.

The insulating layer which preferably is a dielectric layer comprising glass, vitreous ceramics or ceramics is after the firing process under pressure pretension whereby delamination forces occurring under the interior pressure load, which is of variable size depending on the respective radii, will be compensated for within the layer. The heating device as a whole will have an extraordinarily good bonding strength on the usually tube-shaped wall of the flow duct and will permanently withstand even extreme mechanical and thermal loads. Thus optimal production results are always warranted.

Further, the adjustment of the firing temperatures of the deposited layers to the tempering or hardening temperatures of the flow duct wall represents another important aspect of the inventive solution. The method of manufacture can thus be optimized in many ways and can be reduced to few process steps.

The heating device layers are, according to the invention, baked-on foils or baked-on thick-film pastes which are preferably deposited through screen printing, in particular by round-about printing onto the tube body of the hot runner nozzle. This will secure an always uniform distribution of layers, with constant layer thicknesses.

Baking-on of the layers is preferably done by co-firing at temperatures which will not exceed the temperatures required for tempering the metal. Therefore, a grit structure preformed in the metal will be maintained. The dielectric layer will, according to the invention, also tolerate curing temperatures above the firing temperature.

For carrying out the method of the invention, inductive heating of the steel tube which is coated with a green ceramic foil or with a thick-film paste not yet baked-on is particularly well suited since in this process, heat transition will start from the inductively heated steel tube and the layer to be baked on will be heated from inside. Consequently, volatile components such as bonding agents and pressure carriers contained in the thick-film paste can escape readily from the glass-ceramic material system that gradually fuses, without inclusion of residual gas. Thus the formation of bubbles is reliably prevented and the grit structure of the layer will be strictly homogeneous.

The tension-tolerant and strong bond between the ceramic dielectric layer and the flow duct wall is brought about, according to the invention, through providing a targeted pressure

pretension in the ceramic dielectric layer by casewise predetermination of a specific mismatch of the linear thermal expansion coefficient TEC_{DE} of the ceramic dielectric layer to the corresponding value TEC_M of the metallic hot runner tube, with the expansion difference $TEC_{DE} - TEC_M$ amounting to at least $5.0\ 10^{-6}\ K^{-1}$.

According to the invention, the dielectric layer is obtained by baking-on a glass-ceramic material system onto the metal wall of the flow duct within a preferred temperature range from 800 °C to 1,100 °C. This range corresponds to conventional hardening temperatures for most of the commercial tool steel types for hot working.

Moreover, the system of materials which in case of a thick-film paste or a green foil chiefly is vitreous-crystalline comprises at least one preformed glass adapted to wet at a predetermined firing temperature the metal surface and to thus assume at least partially a crystalline state. However, the use of glass ceramics or of a ceramic material is also contemplated.

Additionally or alternatively, the system of materials may comprise at least one further glass that will not crystallize under firing conditions and at least one compound which is a priori crystalline. By optimizing the proportions of the preformed vitreous and ceramic components of the material system, taking into account their respective TEC increments under the conditions of a certain firing process, the ceramic dielectric layer will have a TEC value in the range between $5 \cdot 10^{-6}\ K^{-1}$ and $7 \cdot 10^{-6}\ K^{-1}$.

Further features, details and advantages of the invention will become evident from the wording of the claims and from the following elucidation of embodiments by way of the drawings wherein:

Fig. 1 is a schematic cross sectional view of a hot runner nozzle having a flat layer heating device,

Fig. 2 shows the heating device of Fig. 1 in a developed view, partly folded up,

Fig. 3 is a cross sectional view of another embodiment of a hot runner nozzle having a flat layer heating device,

Fig. 4 shows the heating device of Fig. 3 with a thermosensor in a developed view,

Fig. 5 is a cross sectional view of a further embodiment of a hot runner nozzle having a flat layer heating device,

Fig. 6 shows another type of a heating and thermosensor arrangement and

Fig. 7 shows yet another embodiment of a heating device with a thermosensor.

As a component of an injection mold installation for processing thermoplastics, the hot runner nozzle illustrated in Fig. 1 includes a casing (not shown) for attachment to a manifold (not shown, either), into which casing a generally cylindrical mold mass flow tube 13 can be inserted. A base 17 formed at a tube end winds up flush with the casing and engages the manifold sealingly. The flow tube 13 extends longitudinally in an axial direction. At its end, a nozzle tip 18 is inserted, preferably screwed-in, which tip continues a flow duct 14 formed within the tube 13 up to the plane (not shown) of a die cavity (not to be seen, either). The nozzle tip 18 can also be integral with the flow tube, the function being the same.

Attached to the periphery of the wall 16 of the flow tube 13 that is made of steel is a heating device 10 which is a flat layer heating ensemble having an insulating layer by way of a ceramic dielectric layer 20 directly deposited on the metal, having on top of that a heating layer 22 that may, as schematically indicated in Fig. 2, comprise meandering heating conductor tracks 23, and having an outer cover layer 24 for outwardly covering and electrically insulating the heating conductor tracks 23 as well as the dielectric layer 20 underneath. The heating conductor tracks 23 may have any shape and can be placed onto the insulating layer 20 in variable densities and arrangements, depending on the power required. This makes it possible to achieve a defined temperature distribution within the flow tube 13 as per actual needs.

Another embodiment of a hot runner nozzle 12 is shown in Fig. 3 where the flow tube 13 has no separate nozzle tip 18. The heater layer 22 including the heating conductor tracks 23 is continued, on the ceramic insulating layer 20, up to the outer free end of the mold mass flow tube 13. In this outer zone 19, the cover layer 24 forms at the periphery a sealing face 25 for obturation towards adjacent components. Thus it can be prevented that heat would inadvertently be dissipated to the nearby ambience. The design of the heating layer 22 is evident from Fig. 4. It will be seen that the meandering heating conductor tracks 23 are concentrating in the respective end zones of the flow tube 13, i.e. in the end zone 19 and the fore-region of the base 17. An overall optimum temperature regime is thus made possible, as the power –which can be set to extremely high levels – will be advanced way up to the tip zone of the nozzle 12.

There is no problem with processing even materials of high thermal sensitivity that have a variation window of a few degrees only.

In case the cover layer 24 were not suited for performing the required sealing functions, the flow tube 13 may have at its end zone 19 a steel collar 13' or a flange which comprises an associated peripheral sealing face 25. As shown in Fig. 5, the heating device 10 here is printed onto the cylindrical wall 16 of the flow tube 13 between the base 17 and the collar 13'.

In order to be able to watch or to control both the rise and the progression of the temperature within the flow tube 13 or the flow duct 14, respectively, there is provided between the heating layer 22 and the cover layer 24 at least one layer 28 (Fig. 2) of a PTC material whose resistance increases as the temperature rises. For improved heat conduction, there is between the heating layer 22 and the resistor layer 28 an electrically insulating interlayer 26. Such an interlayer may also be interposed between further layers if required.

The resistor layer 28, which forms a thermoelement, may include conductor tracks 29 – corresponding to those of the heating layer 22 – for measuring the temperature curve as thermosensors (Fig. 4). Expediently, the conductors 29 are in the same plane as the conductor tracks 23 of the heating layer 22 whereby they are commonly protected outwards by the cover layer 24. Thus the extension of the heating device is reduced to a minimum. Alternative concepts of design are shown in Figs. 6 and 7, respectively, for the heating conductors 23 as well as for the thermosensing conductors 29.

Each of the layers 20, 22, 24, 26, 28 is adherently deposited on the tube wall 16 by direct coating and is subsequently baked on under the firing conditions given for the specific materials, resulting in a bonded layer compound. However, by a specific mismatch of the linear thermal expansion coefficient TEC_{DE} of the ceramic dielectric layer 20 relative to the linear thermal expansion coefficient TEC_{M} of the flow tube 13, the baking process of the insulating layer 20 produces a pressure pretension therein. Owing to this tension-tolerant bonding, the insulation layer 20 – as the supporting layer of the heating device 10 – is suited for readily withstanding the pulsating interior pressure loads that are technologically caused by the injection molding process, without an appearance of cracks or other deteriorations at the heating device 10. Since the various function layers 20, 22, 24, 26, 28 of the compund body feature an extraordinarily large adherence among themselves due to their very similar material

compositions, the heating device 10 as a whole will permanently withstand even extreme mechanical and/or thermal loads.

For coating by depositing the various function layers, screen printing with foils and thick-films is suitable. Preferably, though, thick-film screen printing is used together with the round-about printing method.

In this connection it is of advantage if there is in the dielectric layer 20, which preferably is deposited by way of three individual layers, a gap (not shown) in a longitudinal direction of the wall 16 of the flow tube 13. This serves to prevent that individual layers of the dielectric layer 20 would overlap after the deposition, which might lead to undesirable tensions or even to flaking off.

Overall economical processing is attained if parallel to the firing procedure of the dielectric layer 20, the flow tube 13 is inductively hardened. Both for this purpose and also for the following baking-on processes, it is important that the respective firing conditions (firing temperature, duration, cooling rate) be matched to the hardening and tempering temperatures determined by the type of steel used. In particular, the firing temperatures of subsequent layers must not exceed the temperatures for metal tempering so that the already preformed grit of the metal will be preserved. The adjustment can be achieved e.g. through suitable variation of the process parameters of the firing phase. However, an adaption on the basis of specific materials in the thick-film pastes to be used is also possible.

The flow tube 13 as shown in Fig. 1 features a diameter ratio of outer to inner diameter between 1.4 and 2.5, preferably of 2.0, so that with an outer diameter of e.g. 10 mm, the wall 16 will be at least 2.8 mm thick. In operation, the wall will be subject to a pulsating interior pressure of about 2,000 bar and to a temperature of about 300 °C during the injection cycle. The steel of the hot runner tube 13 has a linear thermal expansion coefficient (TEC) of 11 10^{-6} K^{-1} within a temperature range of 20 °C to 300 °C and an elastic modulus of 2 10^{6} bar. The heat treatment temperature required for hardening the material is preferably in the range from 800 °C to 1,050 °C.

Using the round-about printing method, a thick-film dielectric paste is deposited on the metal surface 16 which is roughened in a known manner for improved adherence, the solid portions

of the paste consisting exclusively of a glass that crystallizes in situ at temperatures above 900 °C, with the main components BaO, Al_2O_3 and SiO_2 in an approximate molar composition given by BaO Al_2O_3 $4SiO_2$. The dielectric layer 20 obtained after the firing process has a TEC of 6 10^{-6} K^{-1} in the temperature range from 20 °C to 300 °C.

Owing to the thus resulting TEC mismatch between the metal wall 16 and the dielectric layer 20 of a magnitude of 5 10^{-6} K^{-1}, an originating pressure pretension of about 3,500 bar is to be expected during cooling-down of the dielectric-coated hot runner tube 13 in the temperature range of the purely elastic deformation, i.e. between the transformation temperature of the glass of about 700 °C and room temperature (on the basis of an elastic modulus of the dielectric layer 20 of 2 10^6 bar). The level of the pressure pretension is below the critical limit of the pressure strength of the dielectric proper beginning above 6,000 bar, but is sufficient to reliably prevent tensile stresses in the dielectric layer 20 and thus also in the further layers 22, 24 when the tube wall 16 – of 2.8 mm thickness – of the hot runner tube 13 is subjected to cyclic expansion under a load of 2,000 bar.

The electrical connections 23', 29' for the heating conductor tracks 23 and for the resistor layer 28, respectively, are also made using the thick-film technology, the required contacts being designed in such manner that cable plugging may be employed for power supply and information transfer connections.

The invention is not limited to any of the embodiments described above; rather, it can be modified in many ways. Thus it is possible to provide heating rods within the flow tube 13 that are coated with a heating device as defined above. The tube may also be shaped with an oval or rectangular cross section. Instead of the thick-film pastes, so-called green foils may be used which are fixed on the tube periphery and are subsequently baked on. Tempering of the flow tube 13 may principally be made by formation of martensite or by precipitation hardening, preferably under inductive heating.

It will be realized that an electrical flat heating device is installed by direct coating on the periphery of the wall 16 of a flow tube 13 of a hot runner nozzle 12. That flat heating device 10 comprises: a ceramic dielectric layer 20 directly deposited on the metal tube 13, further a layer 22 consiting of heating conductor tracks 23, and topping that an electrically insulating ceramic cover layer 24.

For coating, the screen printing method is suitable with either foils or thick-films. Preferably, though, the thick-film technology with round-about printing is used for the entire layer structure. Alternatively, the ceramic dielectric layer 20 can be a prefabricated green foil that is fixed on the periphery of the tube 13 and is baked on subsequently.

An important feature of the invention is the development of a tension-tolerant bonding between the ceramic dielectric layer 20 and the hot tunner tube 13 which under operational temperatures is exposed to a pulsating interior pressure load technologically caused by the injection molding process. This load, and the need to heat the flow tube 13 up to temperatures between 300 °C and 450 °C in order to reach operating temperatures, result in elastic expansions of the hot runner tube. The actual degree of deformation will depend on material-bound factors (e.g. elastic modulus) and on technical boundary conditions (operating temperature, tube wall thickness, level of interior pressure). Consequently, the dielectric layer 20 deposited on the steel tube 13 would, under the co-influence of the said factors, be exposed to tensile stresses, if to varying extents; in operation, however, there is a reliable compensation for this by the distinct pressure pretension within the dielectric layer 20.

An extraordinarily good adherence of the dielectric layer 20 on the flow tube 13 of the hot runner nozzle 12 is thus achieved, withstanding readily the delamination forces occurring in radius dependence due to the interior pressure load. It is particularly advantageous that by the heating device 10 of the invention, an extremely high power density can be attained in a narrow space, heat always being produced exactly where it is also carried off. The temperature regime can be realized in a most simple manner, with accurately uniform temperature distribution.

All features and advantages emerging from the claims, the description and the drawings, including design details, spatial arrangements and process steps, may be essential to the invention both per se and in variegated combinations.

List of Reference Symbols

10	heating device
12	hot runner nozzle
13	[mold mass] flow tube
13'	collar / flange
14	flow duct
16	wall
17	base
18	nozzle tip
19	end zone
20	insulating / dielectric layer
22	heating layer
23	heating conductor tracks
23'	connection
24	cover layer
25	sealing face
26	interlayer
28	resistor layer
29	thermosensor / conductors
29'	connection